

SPECTRUM SHARING OF THE INTERNATIONAL MOBILE
TELECOMMUNICATION-ADVANCED AND DIGITAL BROADCASTING IN
THE DIGITAL DIVIDEND BAND

WALID A. HASSAN

UNIVERSITI TEKNOLOGI MALAYSIA

SPECTRUM SHARING OF THE INTERNATIONAL MOBILE
TELECOMMUNICATION-ADVANCED AND DIGITAL BROADCASTING IN
THE DIGITAL DIVIDEND BAND

WALID A. HASSAN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Electrical Engineering)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JANUARY 2013

*To my beloved mother, father, brothers and sister, and to my only love my wife and
to our little princesses Wassan and Leen. Finally to my beloved Jido and dear uncle
Mohanna*

ACKNOWLEDGEMENT

First of all, I would like to express my deepest gratitude to ALLAH (SWT), who guided, helped, and supported me for everything I was able to achieve and for everything I tried but I was not able to achieve.

I wish to express my sincere appreciation and thankfulness to my research supervisor, Prof. Dr. Tharek Abd Rahman for encouragement, motivation, and support in academic, social, financial and technical issues. Truly, I have been overwhelmed by his patience, personal kindness, valuable comments, and advices during my study. Without his continued guidance and help, this thesis would not have been completed.

I have greatly appreciated the golden opportunity from UTM to pursue my PhD, I thank very much all UTM community including every person in (faculties, library, staff, employees, students and labourers). Special thankfulness to all members of WCC, FKE and SPS.

I would like also to thank Mr Jean Phillipe from the European Communication office for his feedback and help. Also Dr Han Shin Jo from Habant University (Korea) for his teaching and assisting and being a co-author on my papers. I would like also to thank Mr Mazer Nekovee from British Telecommuncatio for his advices and notes. Finally I would like to thank Dr Leow and my colleague Mr Sami Tarboshi from Yaman, for all their assistances and advices.

Finally, I can find no words to express my thanks to my parents and all the members of my family, friends and relatives for their constant love, help and support, which motivate me to face the life difficulties.

ABSTRACT

Increasing demand for wireless services has recently led to a radio spectrum shortage. As the spectrum is a limited and scarce natural resource, it should be used as efficiently as possible. In this thesis, a spectrum sharing study is conducted between the Digital Broadcasting (DB) and International Mobile Telecommunication-Advanced (IMT-A) in the 470–862 MHz band. First, a spectrum sharing simulation model based on statistical methodology is proposed in order to identify the requirements for co-existence between IMT-A and DB systems. The results show that co-existence is possible for a limited number of adjacent channels and for a specific sharing scenario. Next, a spectrum sharing analytical model is developed based on the enhancement of a current coexistence model that has been widely used in spectrum sharing research. From this, it is seen that when the DB bandwidth is 8 MHz, a higher IMT-A bandwidth (20 MHz) can co-exist more feasibly with DB than a lower IMT-A (5 MHz) bandwidth. Moreover, in deploying these systems in urban areas, the required separation distances decrease. We then propose an analytical method for evaluating potential compatibility of cognitive radio (CR) systems. This method computes the allowed maximum in-band (PIB) and out-of-band (POOB) transmission power of a CR system based on a victim receiver interference criterion. The PIB and POOB achieved are 16.41 dB higher and 23.76 dB lower, respectively, than those achieved in the traditional method. Finally, we propose a system called Wireless Link using the Global Communication Channel (WLGCC) that enhances spectrum sharing between DB and CR systems within the licensed 470–790 MHz band. The results show that WLGCC does not degrade existing DB service while reliably transmitting information on vacant frequency bands to the CR.

ABSTRAK

Permintaan yang semakin meningkat bagi perkhidmatan wayarles baru-baru ini mengakibatkan spektrum radio tidak mencukupi. Oleh sebab spektrum adalah sumber yang terhad, penggunaannya yang efektif adalah perlu. Dalam tesis ini, satu kajian berkenaan perkongsian spektrum antara sistem Penyiaran Digital (DB) dan sistem Lanjutan-Telekomunikasi Mobile Antarabangsa (IMT-A) telah dijalankan bagi julat frekuensi 470-862 MHz. Pertama, model simulasi perkongsian spektrum menggunakan metodologi statistik dicadangkan untuk mengenal pasti syarat-syarat bagi membolehkan kewujudan bersama sistem IMT-A dan sistem DB. Hasil kajian menunjukkan bahawa kewujudan bersama boleh dijalankan untuk bilangan saluran bersebelahan yang terhad dan senario perkongsian tertentu sahaja. Seterusnya, satu model analisis perkongsian spektrum dihasilkan daripada penambahbaikan kepada model sistem kewujudan bersama sedia ada yang digunakan secara meluas dalam penyelidikan perkongsian spektrum. Daripada analisis ini, dapat diperhatikan bahawa apabila jalur lebar sistem DB adalah 8 MHz, sistem IMT-A dengan jalur lebar lebih tinggi (20 MHz) adalah lebih sesuai untuk wujud bersama dengan sistem DB dibandingkan dengan sistem IMT-A yang mempunyai jalur lebar yang lebih rendah (5 MHz). Selain itu, untuk pengoperasian kedua-dua sistem ini di kawasan bandar, didapati jarak pemisahan yang diperlukan menjadi lebih pendek. Kajian ini kemudiannya mencadangkan satu kaedah analisis untuk menilai kesesuaian sistem radio kognitif (CR). Kaedah ini mengira kuasa penyiaran dalam jalur (PIB) dan di luar jalur (POOB) maksimum berdasarkan kriteria gangguan penerima mangsa. Nilai kuasa PIB adalah 16.41 dB lebih tinggi, dan 23.76 dB pula lebih rendah bagi POOB, jika dibandingkan dengan kaedah konvensional. Akhir sekali, kajian ini mencadangkan satu sistem yang dipanggil Laluan Wayerles menggunakan Saluran Komunikasi Global (WLGCC) yang mampu meningkatkan perkongsian spektrum antara sistem DB dan sistem CR bagi julat frekuensi berlesen 470-790 MHz. Hasil kajian menunjukkan WLGCC tidak mengganggu perkhidmatan sistem DB sedia ada malahan dapat menghantar maklumat dengan baik kepada sistem CR menggunakan saluran frekuensi yang tidak dipakai.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xv
	LIST OF FIGURES	xvi
	LIST OF ABBREVIATION	xx
	LIST OF APPENDICES	xxiv
1	INTRODUCTION	1
	1.1 Introduction	1
	1.2 Research Motivation	3
	1.3 Problem Statement	4
	1.4 Research Objectives	4
	1.5 Research Scope	5
	1.6 Significance and Contribution of the Research Work	6
	1.7 Organization of the Thesis	7
2	THEORY AND LITERATURE REVIEW	10
	2.1 Introduction	10
	2.2 Radio Frequency Spectrum	11
	2.2.1 The UHF band	13

2.3	Spectrum Sharing Overview	16
2.3.1	Dimensions of Spectrum Sharing	17
2.3.1.1	The Space Dimension	18
2.3.1.2	The Frequency Dimension	20
2.3.1.3	The Time Dimension	20
2.4	Impact of Spectrum Sharing on the Spectrum Management	21
2.5	Cognitive Radio	23
2.5.1	The Television White Space Frequencies	23
2.5.2	CR Sharing Method	24
2.5.2.1	Spectrum Sensing Method	24
2.5.2.2	GLD Method	25
2.5.2.3	Beacon Method	26
2.6	Spectrum Sharing Components	26
2.6.1	Transmission	27
2.6.1.1	Signal Bandwidth	28
2.6.1.2	Modulation Schemes	29
2.6.1.3	Unwanted Emission	31
2.6.1.4	Transmitter SEM	33
2.6.1.5	Transmission Antenna	34
2.6.2	Channel and Propagation Model	34
2.6.2.1	Radio Wave Propagation and Pathloss	35
2.6.2.2	Type of Propagation Models	36
2.6.2.3	The Free Space Propagation Model	37
2.6.2.4	Modified Hata Model	38
2.6.2.5	The Point to Multipint	39

	Propagation Model (ITU-R P.1546-4)	
	2.6.2.6 Interference Prediction Model (ITU-R P.452 -14)	39
2.6.3	Reception	41
2.6.3.1	Receiver Sensitivity and Selectivity	42
2.6.3.2	Noise Figure and Noise Floor	42
2.6.3.3	Interference	44
2.6.3.4	Blocking Interference	48
2.6.4	Long Term Interference and Short Term Interference	49
2.7	Coexistence and Compatibility Analysis	49
2.7.1	Deterministic Analysis	50
2.7.2	Statistical Analysis	51
2.8	The DD Spectrum Overview	52
2.9	Services in the 470-862 MHz Band	53
2.9.1	Future Mobile Communication System, IMT-A	54
2.9.1.1	IMT-A Requirement	55
2.9.2	Television Digital Broadcasting	57
2.9.2.1	Benefits of DB	59
2.10	Related Studies of Sharing in Between Mobile and DB Service	60
2.11	Summary	62
3	RESEARCH METHODOLOGY	63
3.1	Introduction	63
3.2	Literature Review	64
3.3	IMT-A and DB Coexistence and Spectrum sharing	65

	3.3.1	IMT-A and DB Coexistence	66
	3.3.2	Spectrum Sharin Techniques	67
	3.4	Summary	67
4		COEXISTENCE AND SPECTRUM SHARING BETWEEN IMT-A AND DIGITAL BROADCASTING IN THE BAND 790-862 MHZ	68
	4.1	Introduction	68
	4.2	System Parameters and Simulation Assumptions	69
	4.2.1	LTE-A	69
	4.2.2	The WiMAX Parameters	70
	4.2.2	The DB Parameters	71
	4.3	Spectrum Sharing and Interference Assessment Methodologies	72
	4.4	Coexistance Model for Mobile-OFDM- Based and DB COFDM-Based	73
	4.4.1	Proposed Method	74
	4.4.2	Assumptions and Sharing Scenario	78
	4.5	The Developed EC Model	79
	4.5.1	The CC Model	79
	4.5.1.1	The Limitation of the CCModel	79
	4.5.2	The CC and EC Model Steps	80
	4.5.2.1	The CC Model Steps	80
	4.5.2.2	The EC Model Steps	84
	4.5.3	Comparisopn Between WiMAX and LTE-A via EC Model	85
	4.5.3.1	Sharing Scenario	86
	4.6	The Proposed Simulation Model	87
	4.6.1	Frequency Plans for Terrestrial DB and Mobile Telecommunication Services in the 790–862 MHz Band	88
	4.6.2	The Significant of the Developed	89

	Simulation	
	4.6.3 The Proposed Simulation	90
	Coexistence Model Setps	
	4.6.3.1 Interference Ass-	91
	-essment Methodology	
	4.6.4 Sharing Scenarios Based on the	94
	Proposed Simulation Model	
	4.7 Spectrum Sharing and Compatibility	97
	Improvement Between Mobile and	
	Broadcasting Services	
	4.8 Summary	97
5	THE COGNITIVE RADIO SPECTRUM	98
	SHARING ENHANCING METHOD THE BAND	
	790-862 MHZ	
	5.1 Introduction	98
	5.2 The ECC 159 CR Spectrum Sharing Methods	98
	5.3 System Parameters and Assumptions	100
	5.4 The Spectrum Sharing between the CR and	100
	the DB	
	5.4.1 Detection Threshold Methodology	101
	5.4.2 The CR Emission Limits for the	102
	Broadcasting Protection	
	Methodology	
	5.4.2.1 The Clutter Loss	103
	5.4.3 Sharing Scenario for the Protection	103
	of DB Service From the CR	
	5.5 The Enhancement to the CR Sensing Model	104
	5.6 The Proposed Spectrum Sensing Method	105
	5.7 Summary	106
6	A SYSTEM FOR ENHANCED SPECTRUM	110
	SHARING BETWEEN DIGITAL	

BROADCASTING AND COGNITIVE RADIO

6.1	Introduction	108
6.2	CR Spectrum Sharing Problems	109
6.2.1	Spectrum Sensing Problems	109
6.2.2	GLD Spectrum Sharing Problems	110
6.3	The WLGCC Concept	110
6.3.1	The WLGCC Deployment	111
6.3.2	The WLGCC Workflow	111
6.3.3	The GCC Frequency Channel Allocation	113
6.4	Proposed Enhancing to the CR method	115
6.5	Methodology and Sharing Scenario	116
6.5.1	Finding the WLGCC System Deployment Parameters	117
6.5.2	WLGCC-TX emission limits	117
6.5.3	Clutter Loss	118
6.5.4	Determining the Compatibility Between the WLGCC and CR Systems	119
6.5.5	Monte Carlo Methodology for Determining the Compatibility between the WLGCC-TX and DB SS	121
6.6	Summary	122

7 RESULTS AND DISCUSSION 123

7.1	Introduction	123
7.2	The OFDM-COFDM based Co-existence Model Results and Discussions	123
7.3	The EC Model Results and Discussions	125
7.3.1	The Attenuation due to SEM and Blocking in EC Model	125
7.3.2	Comparison Results Between the EC and the CC Models	128

7.3.3	The Comparative Results Between WiMAX and LTE-A via EC Model	130
7.3.3.1	IMT-A Candidate as an Interferer into the DB-SS	131
7.3.3.2	DB-BS as an Interferer into the LTE-A BS	135
7.4	The Proposed Simulation Model Results and Discussions	136
7.4.1	LTE-A (BS, UE) Interference With DB-SS	137
7.4.1.1	LTE-A BS as an Interferer	137
7.4.1.2	LTE-A UE as an Interferer	139
7.4.2	DB-BS interference with LTE-A (BS, UE)	139
7.4.2.1	LTE-A BS as a Victim	139
7.4.2.2	LTE-A UE as a Victim Receiver	141
7.5	The CR Method Results and Discussion	143
7.5.1	Spectrum Sensing Detection Threshold (DT) Limitation	143
7.5.2	CR Emission Limits	144
7.6	The Enhanced Sensing Spectrum Sharing Model Results and Discussion	146
7.7	The WLGCC Proposed System Results and Discussion	147
7.7.1	WLGCC System Deployment Parameters	148
7.7.2	Compatibility Between the WLGCC and the CR-UE	150
7.8	Compatibility between the WLGCC and the	152

	DB-SS	
	7.9 Summary	153
8	CONCLUSION	156
	8.1 Conclusion	156
	8.1.1 Conclusions regarding the OFDM COFDM Model	156
	8.1.2 Conclusions regarding the EC Model	157
	8.1.3 Conclusions regarding the CR Enhanced Model	158
	8.1.4 Conclusions regarding the WLGCC System	159
	8.2 Future Works	160
	REFERENCES	161
Appendices	A-D	174-201

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	The RF spectrum characteristics	12
2.2	Interferer bandwidth impact on victim receiver	29
2.3	The relation between the modulation type and the C/N ratio	30
2.4	The Recommended spurious emissions limits	33
2.5	Propagation models	36
2.6	A brief summary on mobile generation and its features	54
2.7	LTE and LTE-A requirement compared to IMT-A requirements	57
4.1	LTE-A parameters in rural and urban area deployment	69
4.2	WiMAX parameters in rural and urban area deployment	71
4.3	DB parameters in rural and urban area deployment	71
4.4	The spectrum sharing scenarios	86
5.1	The CR and DVB-T parameters in rural and urban deployment	100
7.1	WLGCC deployment parameters	135
7.2	The spectrum sharing requirement for interference from DB-BS (8MHz) into LTE-A (20 MHz)	136
7.3	WLGCC deployment parameters	150
7.4	WLGCC coverage	151

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	The RF spectrum	12
2.2	The congested UHF band ‘sweet spot’	14
2.3	The characteristic of the UHF band	15
2.4	The difference of operating frequency properties below and 1 above GHz	15
2.5	The spectrum sharing dimension	18
2.6	The frequency reuse based on separation distance in mobile services	19
2.7	Classification of spectrum based on the application	21
2.8	Underlay (above) and overlay (below) spectrum sharing methods	22
2.9	The schematics of CR	24
2.10	The basic communication blocks	27
2.11	Transmission essential components	28
2.12	Theoretical transmission mask	30
2.13	Spectral transmission using OOK and OFDM modulation	31
2.14	The effect of the unwanted emission	32
2.15	The Unwanted emission components (POOB and Spurious emissions)	32
2.16	The difference between the practical and theoretical mask	34
2.17	The clutter loss parameters	41
2.18	The reception essential components	41
2.19	The reception at the receiver	42
2.20	The ACLR measurement	45
2.21	The ACS measurements	45

2.22	The in band and out of band adjacent channel interference	46
2.23	The blocking effect	48
2.24	Origin of DD band	52
2.25	Different systems and technologies are connected through the all IP networks	55
2.26	The LTE-Advance targets exceed the IMT- requirement in the ITU time line	56
2.27	The deployment of the DB system around the world	58
3.1	The research methodology flow chart	64
3.2	The compatibility methodologies flow chart	65
4.1	PSD $S_v(f)$ of the COFDM-based victim system overlapping with the PSD $S_s(f)$ of OFDM-based interfering system	75
4.2	The mask attenuation calculation based on the SEM breaking points.	82
4.3	Preferred channel arrangement	88
4.4	Simulation model flowchart to determine the minimum separation distance	90
4.5	Sharing of 790–862 MHz band between LTE-A (5MHz) and DB service.	95
4.6	Sharing of 790–862 MHz band between LTE-A (20MHz) and DB service	95
5.1	The schematic of CR operation	99
5.2	The compatibility scenario between the DB and the CR	104
5.3	Adjacent channel sharing scenario between CR and DB service	104
6.1	Proposed deployment of the WLGCC system	111
6.2	WLGCC workflow for allocating the TVWS	112
6.3	TVWS in the UHF band (0–1000 MHz)	114
6.4	Allocation of WLGCC system on channel 49	114
6.5	WLGCC enhancement of CR spectrum sharing methods	115
6.6	Calculation of the coverage of the WLGCC based on C/I criterion	120

6.7	Compatibility between the WLGCC-TX and DB-SS	121
7.1	Comparison of the achieved minimum separation distances between A-MCL and the proposed method	124
7.2	Comparison between the attenuation due to DB SEM and LTE-A (5, 20 MHz) receiver blocking	126
7.3	Comparison between the attenuation due to LTE-A (5 MHz) SEM and DB-SS receiver blockin	127
7.4	Comparison between the attenuation due to LTE-A (20 MHz) SEM and DB-SS receiver blocking	127
7.5	Comparison between the CC and EC models in the interference from 8 MHz DB into 20 MHz IMT-A	128
7.6	Comparison between the CC and the EC models in the interference from 8 MHz DB into 20 MHz IMT-A	129
7.7	The sharing of DB and IMT-A in adjacent channel sharing scenario	130
7.8	Spectrum sharing scenario in which either LTE-A (5 MHz) or WiMAX (5 MHz) is interfering with DB (8 MHz) in a rural environment	131
7.9	Spectrum sharing scenario in which either LTE-A (5 MHz) or WiMAX (5 MHz) is interfering with DB (8 MHz) in an urban environment	132
7.10	Spectrum sharing scenario in which either LTE-A (20 MHz) or WiMAX (20 MHz) is interfering with DB (8 MHz) in an rural environment	133
7.11	Spectrum sharing scenario in which either LTE-A (20 MHz) or WiMAX (20 MHz) is interfering with DB (8 MHz) in an urban environment	134
7.12	Interference from 5 MHz LTE-A for 8 MHz DB-SS in rural and urban areas.	137
7.13	Interference from 20 MHz LTE-A for 8 MHz DB-SS in rural and urban areas.	138
7.14	Interference from DB-BS for 5 MHz LTE-A in rural and urban areas	140

7.15	Interference from DB-BS for 20 MHz LTE-A in rural and urban areas	140
7.16	Interference from DB-BS for 5 MHz LTE-A in rural and urban areas	141
7.17	Interference from DB-BS for 20 MHz LTE-A in rural and urban areas.	142
7.18	The sensing detection threshold as a function of operating frequency from 470MHz to 790MHz	143
7.19	The CR PIB in order not to affect the DB reception as a function of distance in rural and urban areas	144
7.20	The CR POOB in order not to affect the DB reception as a function of distance in rural and urban area	145
7.21	POOB comparison between ECC159 and the proposed method	146
7.22	PIB comparison between ECC159 and the proposed method	147
7.23	PIB_{WLGCC} as a function of ACIR value for five separation distances between WLGCC-TX and DB-SS (d2)	148
7.24	$POOB_{WLGCC}$ as a function of ACLR value for two separation distances between the WLGCC-TX and DB-SS	149
7.25	WLGCC power received by CR-UE in rural and urban environments	151
7.26	Probability of interference between the WLGCC and the DB-SS in rural environment	152
7.27	Probability of interference between the WLGCC and the DB-SS in urban environment	153

LIST OF ABBREVIATIONS

2G	-	Second Generation
3G	-	Third Generation
4G	-	Fourth Generation
ACIR	-	Adjacent Channel Interference Ratio
ACLR	-	Adjacent Channel Leakage Ratio
ACS	-	Adjacent Channel Selectivity
AD	-	Antenna Discrimination
A-MCL	-	Advanced Minimum Coupling Loss
APT	-	Asian Pacific Telecommunity
ASO	-	Analogue Switch Off
ATSC	-	Advance Television System Committee
BS	-	Base Stations
C/I	-	Carrier-to-Interference Ratio
C/N	-	Carrier-to-Noise Ratio
C/N+I	-	Interference-to-Interference-Pulse-Noise Ratio
CC	-	Current Coexistence
CEPT	-	Conference for Postal And Telecommunity
CL	-	Clutter Loss
COFDM	-	Coded Orthogonal Frequency Division Multiplexing
CR	-	Cognitive Radio
CRS	-	Cognitive Radio System
DB	-	Digital Broadcasting
dBc		Decibels relative to the carrier
DB-SS	-	DB Subscriber Station
DD	-	Digital Dividend

DL	-	Downlink
DTMB	-	Digital Terrestrial Multimedia Broadcast
DTTB	-	Digital Terrestrial Television Broadcasting
DVB-H	-	Digital Video Broadcasting – Handheld
DVB-T	-	Digital Video Broadcasting – Terrestrial
EC	-	Enhance Co-existence
E-MCL	-	Enhanced Minimum Coupling Loss
EM	-	Electromagnetic Fields
ESM	-	Exclusive Spectrum Management
E-UTRA	-	Evolved-UMTS Terrestrial Radio Access
FCA	-	Frequency Channel Assignment
FCC	-	Federal Communication Commission
FDD	-	Frequency Division Duplex
FDMA	-	Frequency Division Multiple Access
FS	-	Fixed Service
FSO	-	Frequency Separation Offset
GB	-	Guard Band
GCC	-	Global Communication Channel
GE-06	-	Geneva Agreement -2006
GE-89	-	Geneva Agreement-1989
GLD	-	Geolocation Database
GPS	-	Global Positioning System
HDTV	-	High Definition Tv
HSM	-	Hierarchical Spectrum Management
I/N	-	Interference-to-Noise Ratio
IMT-A	-	International Mobile Telecommunication– Advanced
ISM	-	Industrial, scientific, and medical
ITU	-	International Telecommunications Union
IP	-	Internet Protocol
ISDB-T	-	Integrated Service Digital Broadcasting – Terrestrial
LAN	-	Local Area Network

LOS		line-of –sight
LTE	-	Long Term Evolution
LTE-A	-	Long Term Evolution – Advanced
MCL	-	Minimum Coupling Loss
MIMO	-	Multiple Input And Multiple Output
MPEG	-	Moving Picture Experts Group
NB	-	Necessary Bandwidth
OFDM	-	Orthogonal frequency division multiplexing
OFDMA	-	Orthogonal Frequency Division Multiple Access
OOK	-	On Off Shift Keying
OSA	-	Opportunistic Spectrum Access
PIB	-	Power In-Band
POOB	-	Power Out-Of-Band
PIB-5		Power In-Band for 5 km away from DB receiver
PIB-10		Power In-Band for 10 km away from DB receiver
PR	-	Protection Ratio
PSD	-	power spectral density
PSTN	-	Public Switched Telephone Network
RF	-	Radio Frequency
RN	-	Reference Network
RPC	-	Reference Planning Configures
RRC-06	-	Regional Radiocommunication Conference-2006
SC	-	Spectrum Common
SEM	-	Spectrum Emission Mask
SNF	-	Single Frequency Network
SS	-	Subscriber Station
TDD	-	Time Division Duplex
TDMA	-	Time Division Multiple Access
TVWS	-	Television White Space
UE	-	User Equipment
UHF	-	Ultra High Frequency
UL	-	Uplink
UWB	-	Ultra Wide Band

WiMAX	-	Worldwide Interoperability for Microwave Access
WLGCC	-	Wireless Link Based On The Global Communication Channel
WLGCC-TX	-	WLGCC Transmitter
WRC-07	-	World Radio Conference-2007
WRC-12	-	World Radio Conference-2012
ZGB	-	Zero Guard Band

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Related Publications	174
B	Summary of Previous Spectrum Sharing Studies	176
C	Related Coexistence and Spectrum Sharing Parameters	191
D	The Malaysian Spectrum Chart	200

CHAPTER 1

INTRODUCTION

1.1 Introduction

The use of wireless applications is growing daily. As the spectrum is a limited viable resource, with new systems needing to share licensed frequencies with existing services, spectrum sharing and compatibility studies have become emerging research topics. Results of such studies can help guarantee that, within a shared frequency band, new systems can operate without performance degradation while existing services are protected. Such outcomes are considered necessary in order to save costs by preventing expected harmful interference impacts between new and former systems.

This thesis focuses on co-existence and spectrum sharing between the up-and-coming mobile communications system known as the International Mobile Telecommunication-Advanced (IMT-A) and the Digital Broadcasting (DB) services within the 790–862 MHz sub-band of the congested ultra high frequency (UHF) band. By developing various co-existence and spectrum sharing models, this study aims to develop a co-existence requirement for these two services when sharing a portion of the spectrum. Additionally, the use of cognitive radio (CR) to enhance spectrum sharing between these two services is investigated.

The introduction of DB with high spectral efficiency has helped to trigger a phasing-out of analog broadcasting. By using advanced technologies such as coding and compression, DB can more efficiently use the UHF spectrum; while analog broadcasting requires 8 MHz of bandwidth per channel, DB can deliver up to 14 channels over the same 8 MHz. This efficient use of spectrum has freed up a segment of the UHF band called the digital dividend (DD) band, resulting in a previously unthinkable availability of free spectrum within the UHF band. Since implementation of the Stockholm Plan in 1961, the lower UHF band (i.e., 470–862 MHz) had been reserved for analog broadcasting [1, 2]. However, at the latest Regional Radio Communication Conference in 2006 (RRC-06), all participating countries were given a mandate to migrate from analog to DB no later than 2015. This analog switch off (ASO) is extended to 2020 for countries that cannot meet the 2015 deadline, as well as to countries not present at RRC-06 [3].

The evolution of the mobile systems from voice-only to multimedia service has led to a corresponding increase in demand on the radio spectrum. The IMT-A is the next generation of mobile telephony standard [1] that aims to provide more multimedia service at higher quality; it will be available after the next World Radio Conference-2012 (WRC-012). The two main challenges in implementing IMT-A, which exemplify the demand created on the spectrum by such new technologies, are supporting a bandwidth of up to 100 MHz per channel and accommodating a high data rate. To cope with the introduction of both IMT-A and a new terrestrial broadcasting platform (i.e., DB), the World Radio Conference-2007 (WRC-07) passed two unanimous resolutions concerning the 790–862 MHz band: the first of these (224 of WRC-07) stated the intention of the administrations to protect the existing broadcasting system from the mobile system, while the second (794 of WRC-07) allocated the 470–806/862 MHz band to both mobile and broadcasting services as co-primary basis starting in 2015. Furthermore, the resolution (794 of WRC-07) requested that studies of sharing between the two services be conducted [4]. Based on this, a wide range of research has been conducted to investigate the preferred frequency channel assignment (FCA) of mobile services within the DD band. As of this time, two FCA proposals have been submitted to the International Telecommunications Union (ITU): the European Harmonized FCA, submitted by the

European Conference of Postal and Telecommunications Administrations (CEPT) in 2008 for Region 1 (Europe and Africa) [5] and the Asia–Pacific Telecommunity (APT) FCA proposal for Region 3 (Asia and the Pacific), submitted in 2010 [6].

1.2 Research Motivation

As the ITU has assigned the 470–862 MHz band to terrestrial DB and the IMT-A service will operate in the 791–862 MHz band [7], it is evident that these two services must share a spectrum, which might lead to performance degradation. As a result, studies of interference between the two services are required in order to ensure primary service protection (i.e., DB reception) and to maintain the quality of service of the newly introduced system (i.e., IMT-A). Such studies are needed to quantify possible compatibilities between the two services and to propose practical guidelines for efficient spectrum usage and reliable services.

Until all of the ITU-participating countries switch to DB (which is expected to occur between 2012 and 2020 [3]) and the commercial deployment of IMT-A (expected in 2015 [8]), the topic of spectrum sharing will be an important and challenging one between the two services. All research opinions, recommendations, and results will be considered as input notes to the upcoming WRC-12 and WRC-15, demonstrating that studies designed to find the most efficient approaches for utilizing the shared radio spectrum still represents an open area of research. One of the challenges facing the ITU is that spectrum sharing studies are difficult to standardize globally, as each country has its own spectrum planning scheme. Thus, each country must conduct its own spectrum sharing studies.

Although several studies of spectrum sharing between IMT-A and DB have already been conducted within the DD band and other bands, as shown in Appendix B, this study motivation for research is to further develop expected spectrum sharing scenarios as well as new spectrum sharing models. In addition, this study will

investigate enhancement of the existing model of spectrum sharing between the two systems.

1.3 Problem Statement

IMT-A and DB services will need to share the existing spectrum while operating in a compatible manner. Both co-channel and adjacent channel interference may occur between the two services, with co-channel interference certain to occur between two territories or countries. If, for example, country A completes the ASO phase and deploys mobile services in the 790–862 MHz sub-band, while neighboring country B is in a transition period of switching from analog to DB and still using the 790–862 MHz sub-band for broadcasting services, then co-channel interference will occur in radio communication between the two countries. Likewise, adjacent channel interference may occur in one country between two services operating within the same geographical region. For instance, if a country has deployed mobile service in the 790–862 MHz sub-band where DB service is already operational in the 470–790 MHz band, then these two systems will experience adjacent channel interference with each other even though they are separated in the frequency domain. Such interference is more challenging when both services are active and cover the same area (i.e., a co-cited situation). Thus, the development of analytical and simulation models is needed to assess possible interference between the two systems and to find their necessary compatibility requirements. Enhancement of spectrum sharing between two systems can be considered as a viable solution to interference.

1.4 Research Objectives

The objective of this study is to evaluate the performance of a primary service (i.e., DB) when a new service (i.e., IMT-A) is introduced into the 790–862 MHz sub-band, and vice versa. This will be done by investigating expected sharing scenarios

when both services are deployed in the same geographical area (i.e., adjacent channel sharing scenarios) as well as when they share a frequency in two different geographical locations (i.e., co-channel channel sharing scenarios). The results of these assessments will set co-existence requirements for deploying both services. This result will also help fulfill the ITU-R study request concerning the sharing of these two services, demonstrating that spectrum sharing enhancement is required to maximize utilization of the spectrum.

Based on the statement of the research problem, the objective of the study can be broken down as follows:

- To investigate the interference impact of introducing the new mobile standard IMT-A in order to ensure protection of the DB service. The results of this will set co-existence requirements, including the required minimum separation distance and the width of the frequency guard band;
- To carry out a performance measurement of the new service (IMT-A) as it is affected by the primary service in order to find the required separation distance and guard band; and
- To investigate CR as a solution for enhancing spectrum sharing between IMT-A and DB within the DD band.

1.5 Research Scope

To carry out these research objectives, the scope of the study must include an identification of the system parameters of both services, as well as recommendations as to how each service should be deployed in different areas. Statistical methodology will be utilized to assess interference and evaluate performance. The IEEE 802.16m Worldwide Interoperability for Microwave Access (WiMAX) and Long Term Evolution-Advanced (LTE-A) systems will be used to represent the IMT-A service, while Digital Video Broadcasting-Terrestrial (DVB-T) will be used as a DB service. Various CR techniques will be investigated and applied in order to optimize spectrum sharing within the 790–862 MHz band.

The scope of the study covers the following:

- Literature review of current research, technical reports, and recommendations that have been published regarding the co-existence of IMT-A and DVB-T;
- Determination of the technical parameters of both mobile and DB services, along with their propagation models, interference criteria, and future frequency sharing scenarios;
- Determination of co-existence methodologies in order to evaluate the interference effect. For this, both mathematical and simulation models are considered;
- Development of an analysis tool to assess co-existence between DB and IMT-A;
- Investigation of CR spectrum sharing methods;
- Development and modeling of a proposed novel method for enhancing spectrum sensing techniques in order to achieve optimal spectrum usage within the UHF band; and
- Proposal of a system to enhance the spectrum sharing model of CR.

1.6 Significance and Contribution of the Research Work

The main significance of this research is that it assesses ways to maximize the utilization of the limited radio spectrum resource. Furthermore, as no IMT-A system will be deployed until 2015 [8], the findings of this research will be important to member countries of the ITU, as it will allow them to predict future scenarios and the consequences of deploying both services. The results of this study will provide recommendations for deployment of IMT-A and requirements for protection of the DB service. The study also introduces new co-existence models based on mathematical and simulation modeling. Finally, it introduces a new spectrum sensing sharing model and a proposed system to enhance spectrum sharing methods in the CR. Together, these contributions will be useful for the deployment of services within the same or adjacent geographical areas in such a manner that primary service is protected and higher spectrum utilization is achieved.

The contributions of this research are as follows:

1. An analytical model to evaluate interference from IMT-A orthogonal frequency division multiplexing (OFDM) based on DB broadcasting-coded OFDM (COFDM) and using statistical methodology is developed (Chapter Four, Section 4.4);
2. An analytical model to evaluate the interference between mobile and broadcasting services, and vice versa, based on the spectrum emission mask (SEM) of the interferer and the interference-to-noise (I/N) ratio of the victim receiver is developed using statistical methodology (Chapter Four, Section 4.5);
3. A simulation model based on statistical methodology is proposed to evaluate possible interference for DB victim receivers resulting from implementation of the ITU digital plan as well as for mobile service resulting from the European FCA (Chapter Four, Section 4.6);
4. A CR spectrum sensing model to enhance spectrum sharing between IMT-A and DB within the DD band is developed (Chapter Five, Section 5.5); and
5. A new system for enhancing spectrum sensing and geo-location database (GLD) sharing methods in CR is introduced (Chapter Six, Section 6.3).

1.7 Organization of the Thesis

In compliance with the theoretical and practical aspects of the study, this thesis consists of eight chapters, each providing a detailed discussion of the respective issues.

- Chapter One provides an introduction and background to the research, in order to demonstrate the importance of the topic and shape the lines of argument in the research. Following this, the motivation for research, statement of the problem, objectives of the research, research scope, significance of the study, and, finally, the thesis outline are presented.

- The theory and the literature review are presented in Chapter Two, which provides the theory behind the relevant work as well as recommendations relating to DB and IMT-A systems, co-existence requirements, spectrum sharing methods, and related work. As co-existence between the new mobile service (IMT-A) and the new broadcasting platform DVB-T services is a currently popular topic for research, the literature review will proceed until the writing of the final draft of this thesis. The chapter also reviews the related studies in co-existence and spectrum sharing.
- In Chapter Three, the methodologies used to achieve the results of this study are provided. These are divided into five parts: a literature review, development of an analytical model of a sharing technique to evaluate the co-existence requirements between IMT and DB services, investigation of the CR as a spectrum sharing technique, enhancement of CR spectrum sharing methods, and proposal of a new system to enhance CR spectrum sharing methods.
- Chapter Four provides a detailed description of co-existence between IMT-A and DB within the DD band. This chapter represents the core of the research conducted to formulate the current problem of interference between these two systems. Statistical methodology is used to understand the conditions for compatibility between the systems, and the results of this chapter will clarify and call attention to the consequences of interference impact between the two systems when they share the 790–862 MHz spectrum.
- In Chapter Five, CR spectrum sharing techniques for enhancing the co-existence between IMT-A and DB within the DD band are investigated. The chapter provides details of current spectrum sensing methodologies and introduces a model for enhancing CR system spectrum sensing methods.
- In Chapter Six, a new system for enhancing the CR spectrum sharing model is proposed. Additionally, this chapter provides arguments and discussion pertaining to the new system. A justification of the utility of the new system and sharing scenarios to investigate its validity are provided.
- Chapter Seven provides research results and discussion. An extensive analysis of co-existence and spectrum sharing methodologies is conducted.

- Finally, Chapter Eight is devoted to the overall conclusions of the research. This is followed by a discussion of future work needed to enhance co-existence between DB and IMT-A system.

APPENDIX A

PUBLICATIONS

Journal Papers

1. **Walid A Hassan.**, *et al.* Spectrum Sharing Method for Cognitive Radio in TV White Spaces.KSII Transactions on Internet and Information Systems (TIIS). 2012. 6 (8): 1894-1912.
2. **Walid A. Hassan.** A Spectrum Sharing Model for Compatibility between IMT-Advanced and Digital Broadcasting.KSII Transactions on Internet and Information Systems (TIIS). 2012. 6 (9): 2073-2085.

Conference Papers

1. **Walid A. Hassan**, Tharek Abd Rahman “Compatibility between Cognitive Radio and the Terrestrial Digital Broadcasting Services in the Digital Dividend Band”. *Proceedings of PIERS 2012 in Kuala Lumpur*, Malaysia. 27-30 March, 2012.)
2. **Walid A. Hassan**, Yusuf Abdulrahman, Tharek Abd Rahman “The Digital Dividend Spectrum in Asia.”. *Proceedings of PIERS 2012 in Kuala Lumpur*, Malaysia. 27-30 March, 2012.)

3. **Walid A. Hassan**, Tharek Abd Rahman “Compatibility between the IMT-A service with digital broadcasting in the digital dividend band”. ICWCA 2012, 8 - 10 October 2012. Kuala Lumpur, Malaysia. IEEE/IET. (Accepted, in press)
4. Yassir A. Ahmad, **Walid A. Hassan**, Tharek Abd Rahman. Studying Different Propagation Models for LTE-A System.. *The International Conference on Computer & Communication Engineering 2012, ICCCE 12*, Kuala Lumpur, Malaysia. July 12. IEEE (Accepted) (*In Press*).
5. Mastaneh Mokayef. **Walid A. Hassan**, Yassir A. Ahmad, Tharek Abd Rhman. Optimizing the coexistence between HAPS platform and terrestrial system in 5.7GHz band. *The International Conference on Computer & Communication Engineering 2012, ICCCE 12*, Kuala Lumpur, Malaysia. July 12. IEEE (Accepted) (*In Press*).
6. Mastaneh Mokayef. **Walid A. Hassan**, Yassir A. Ahmad, Tharek Abd Rhman .Enhancement of Coexistence between HAPS and Terrestrial System in 5.8 GHz Band *Proceedings of PIERS 2012 in Moscow*, Russia. 19-23 August, 2012. (Accepted). (*In Press*)
7. Mastaneh Mokayef. **Walid A. Hassan**, Yassir A. Ahmad, Tharek Abd Rhman .Utilizing ATPC Scheme to Facilitate Sharing between HAPS and Terrestrial in 5.8 GHz Band *Proceedings of PIERS 2012 in Moscow*, Russia. 19-23 August, 2012. (Accepted). (*In Press*)
8. Mastaneh Mokayef. **Walid A. Hassan**, Yassir A. Ahmad, Tharek Abd Rhman .Applicability of DCA in HAPS-based Systems in 5850--7075 MHz Band . *Proceedings of PIERS 2012 in Moscow*, Russia. 19-23 August, 2012. (Accepted) (*In Press*)